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CREEP MECHANISMS IN ASPHALTIC CONCRETE

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ABSTRACT

Creep in asphaltic concrete, known as permanent deformation or rutting is one of the main failure mechanisms within the road infrastructure network. The Australian pavement design process however, does not incorporate procedures for minimising creep and instead relies on empirical test procedures linked to ranking material performance in the laboratory. The paper reviews current international laboratory test methods employed for the prediction of creep in the field and considers the development of mechanistic based laboratory methods that would more accurately simulate the stress, temperature and boundary conditions of the pavement in the field.

KEYWORDS

Creep, asphalt, asphaltic concrete, permanent deformation, laboratory testing.

INTRODUCTION

Australia has one of the largest road networks (1.69 million km) in the world and as a result expends significant amounts of government funding (in current prices over $4.7 billion) on the maintenance of that network (Shrapnel 2011). Asphaltic concrete (asphalt) is used extensively in the urban environment component of the network and for example over 10 million tonnes of asphalt is produced annually at a cost of $1 billion (AAPA 2011). The reduction in maintenance costs of asphalt will provide significant saving to the nation. Asphalt exhibits structural distress in the form of fatigue cracking and/or creep deformation. While fatigue models based on the original Shell criteria have been well established (Austroads 2012) and applied in mechanistic design there has been little success with the development of predictive creep relationships for inclusion in the mechanistic design process.

CREEP IN ASPHALT

Creep in asphalt normally refers to the time-dependent accumulation of strain produced by repeated traffic loads. After load removal some part of the deformation can be recovered and another part remains in the asphalt mixture. The permanent deformation or rutting is especially evident when heavy and slow vehicular loads occur (Garba 2002; Öztürk 2007) and rutting accrues mostly under the wheel path resulting from heavy traffic loads on the roads (Yang et al. 2005). The extent of rutting in asphalt is dependent on a number of factors including temperature, load duration, stress levels, material properties and mix design. In order to design for permanent deformation, mix design performance must be able to be evaluated within the laboratory and predictive relationships established. The laboratory test conditions need to comply as closely as possible with the conditions of the pavement in the field such as temperature and loading conditions.

Rutting is generated by the two mechanisms of densification and shear deformation. Densification is a result of poor compaction during construction and usually happens in the early life of a pavement. In this process, aggregates tend to pack more closely under traffic pressures (post construction compaction) and a reduction of air voids in the mixture occurs. Shear deformation (or lateral movement of materials) is the more important factor and is where the asphalt is pressed down under tyre pressure and displaced upwards on either side of the tyre path (Aksoy & Iskender 2008; Cai 2013). Research undertaken by Eisemann and Hilmar to evaluate mechanisms of permanent deformation (Eisenmann & Hilmar 1987) concluded that although in the initial stages, densification or traffic compaction is the primary factor for developing initial rutting, shear deformation is considered as the main factor to develop permanent deformation during the pavement's lifetime.

Permanent deformation of asphalt mixtures following the classical creep curve and has the normal three stages of primary, secondary stage and tertiary (Oscarsson 2011). In the primary stage, permanent strain develops quickly due to initial densification. The majority of an asphalt pavement life is in the secondary stage where there is an almost constant rate for developing rutting. There is accelerated rutting in the tertiary stage.

THE AUSTRALIAN CREEP TEST

The current creep test was originally issued as Australian Standard, AS 2891.12.1995 in November 1995 (*Methods of sampling and testing asphalt* 1995). The test procedure was improved in 2008 in parallel with the Austroads mix design procedures (Alderson & Hubner 2008). The test procedure uses two specimen sizes: a 100 mm diameter for asphalt mixes with a maximum particle size 20 mm and 150 mm diameter for mixtures with a maximum particle size of 40 mm. In summary the test procedure consists of a 200kPa cyclic vertical stress with a termination strain of 30000 microstrain and a termination pulse count of 40000. The main parameter derived from the creep test is the minimum slope of the accumulative strain versus number of load cycles curve (Figure 1). The minimum slope is the point of inflection of the curve.

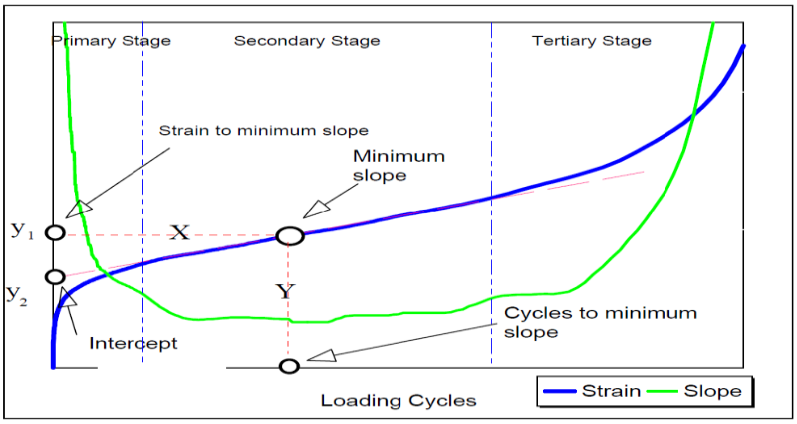

Figure 1. Dynamic creep diagram (Alderson & Hubner 2008)

Concern has been expressed in both Australia and overseas about the ability of the dynamic creep test to adequately indicate an asphalt mix's susceptibility to rutting in situ. This concern is generated from a comparison of the dynamic creep test outputs to data that has been collected from field trials (Oliver et al. 1995). One problem with using the existing test is that it does not accurately simulate the conditions of the pavement in the field (Aksoy & Iskender 2008; Huang & Zhang 2010). The failure to duplicate field behaviour is attributed to the fact that the asphalt subjected to tyre loading in a pavement is surrounded by more asphalt mixture which provides a measure of confinement.

THE CURRENT RESEARCH

The current research extends the use of the existing Australian standard by the use of a full or quasi confining stress to better replicate field conditions. The use of quasi-confinement by use of a smaller platen on an oversize asphalt sample has been explored with mixed success previously by Bullen and Preston (Bullen & Preston 1992) and Austroads (1995). Later Nunn et al (Nunn, Brown & Guise 1998) proposed the extension of the Nottingham Asphalt Tester using a similar approach. That work has been encapsulated in the current European standard EN12697-25A (EN 2005) using a 96 mm diameter platen with 150 mm diameter specimen. It is worth noting that Austroads (1995) found that radial splitting (bursting) occurred for the arrangement recommended in EN 12697-25A due to the lack of an adequate confining annulus of asphalt.

The intent is to extend the earlier work by exploring the platen to sample diameter effects through viscoelastic modelling and experimental work. This would be augmented by the use of a hoop stress applied through a confining ring, similar to that used in geomechanics for odometer testing (soil consolidation) (Figures 2 and 3).

Figure 2. Existing creep test

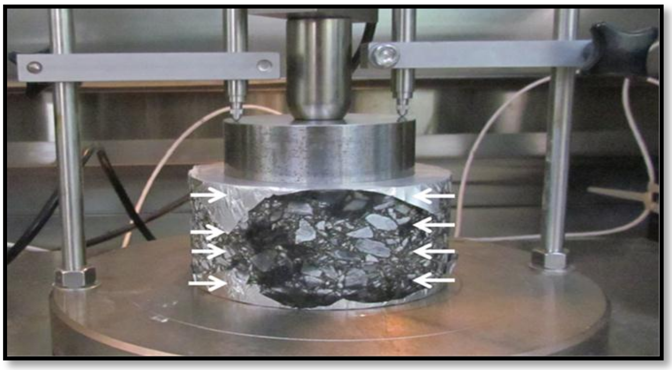

Figure 3. Using smaller top platen size

Similar to fatigue modelling, the complex stress distributions within the small laboratory specimens, and the different loading types and magnitudes in the field make it difficult to replicate field rutting in the laboratory. With appropriate numerical modelling it should be possible to develop a calibrated model that will enable field rutting prediction (with shift factors) similar to that now widely used in fatigue analysis and mechanistic design.

MODELLING OUTCOMES

Elastic modelling has been undertaken to provide better insight into the overall research methodology. An elastic model of pavement with 1000mm×1000mm dimension under 750 kPa stress (with100mm diameter; to simulate tyre pressure) was set up to simulate field conditions. For laboratory modelling, a specimen with 150mm diameter and 50 mm height, under varying platen sizes (50mm, 80mm, 100mm, 120mm, 150mm) was subjected to a 750 kPa axial stress and different confining pressures (0 kPa, 100 kPa, 200 kPa, 300 kPa, 400 kPa). Figure 4 shows a schematic representation of the laboratory specimen.

As shown in Figure 5, it is seen that when the test procedure uses smaller platens on samples, the test provides a restraining annulus of asphalt. The laboratory evaluation then becomes a closer approximation of actual field conditions.

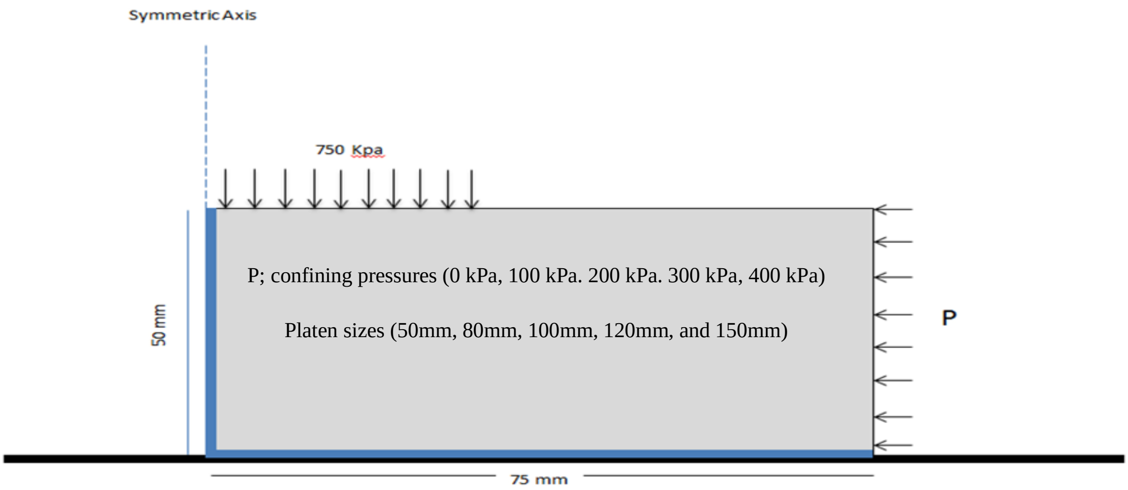

Figure 4. Schematic of model

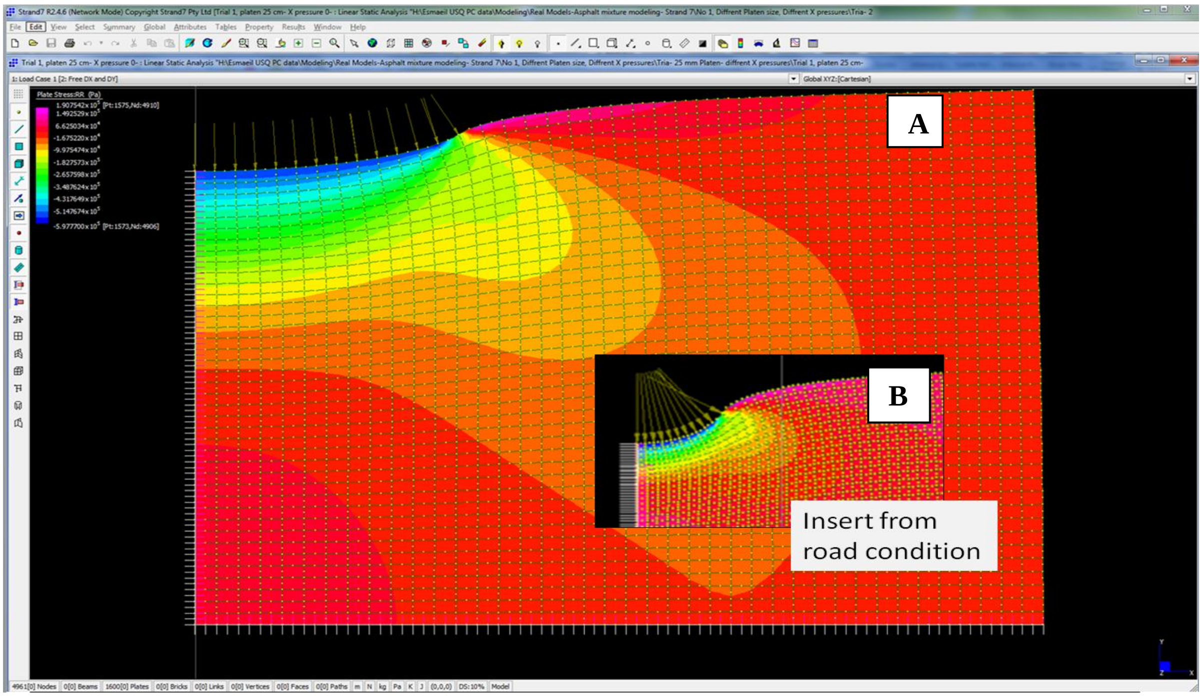

Figure 5. A) Specimen with 150mm diameter and 50mm height, under 50mm platen size, and expose to 750 kPa axial load. B) The elastic model of a road pavement under 750 kPa load

EXPRIMENTAL RESULTS

Table 1. Creep test results at 750 kPa tyre pressure (note: * data in brackets is the minimum creep slope for a 100mm/ 100mm sample at the same air voids)

Sample No.	Platen/Sample size	Tyre Pressure	Air voids	Creep curve		Minimum creep slope
				Stage 1	Stage 2	
	(mm)	kPa	(%)	Cycles	Cycles	(µs/cycle)
1	50 mm/100 mm	750	4.33	5600	52000	0.339 (2.8)*
2	50 mm/150 mm	750	5.19	6000	42000	0.813 (5.4)*
3	100 mm/100mm	750	5.84	800	5600	7.96
4	50 mm/ 100 mm	750	5.18	6000	36000	0.484 (7.2)*
5	100 mm/100mm	750	4.94	1400	-	3.73
6	100 mm/100mm	750	5.18	600	-	6.98
7	100 mm/100mm	750	4.7	1800	-	3.67

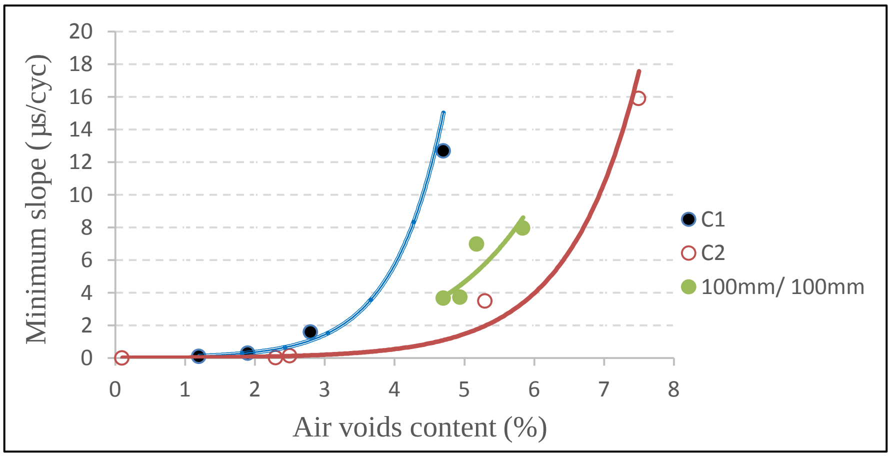

Figure 6. effect of air voids on minimum slope for 100mm/ 100mm compare to literature

Dynamic creep testing with different platen and sample sizes has been performed and the test outcomes are presented in Table 1. The air void content versus minimum slope (Figure 6) for the 100mm/100mm tests has been plotted and compared with previous data from two different typical Australian mixes (C1 and C2) asphalt mixes (Oliver et al. 1995).

Based on the limited testing undertaken the following observation may be made:

1- A comparison with previous research of 100mm/100mm test data regarding minimum slope and air voids indicates that mix creep performance is typical (based on current standards).
2- Even allowing for air voids variation, the test data for 50mm/100mm, and 50mm/150mm demonstrate an approximate order of magnitude reduction in minimum slope and a corresponding increase in secondary creep life compared to the standard 100mm/100mm samples.
3- The limited data to date demonstrates that use of a confining pressure in the form of a confining annulus of asphalt significantly modifies the creep behaviour of the samples to be more representative of in situ behaviour.

CONCLUSION

The preliminary experimental and elastic modelling indicates that the research approach has a sound basis and should serve to extend the current non-representative testing methodologies set out in the current Australian and European Standards.

Calibration of a viscoelastic model with laboratory data will enable the creation of a model able to be extended into the basis of a mechanistic creep design process better able to predict the creep field performance of asphalt. Such a mechanistic design process for asphalt creep will benefit the road construction industry and the macroeconomic development of the nation through better utilisation of road maintenance funds.

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